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ABSTRACT

Cognitive performance on "An Inventory of Piaget's Developmental Tasks" (IPDT) was related to the Scholastic Aptitude Tests and performance in both college chemistry lecture and laboratory classes. The IPDT is a valid and reliable 72-item, untimed, multiple-choice paper and pencil inventory with 19 subscales representing different Piagetian tasks. Subjects (N=225) from two different levels of introductory chemistry courses participated in the study. IPDI scores were significantly correlated with SAT's and placement data. Although correlations with course grades were low, "A" students were higher than others in Piagetian development, particularly for the higher level course. Males outperformed females on the IPDT even when course grades were similar. Weakest areas of development as indicated by subscale scores are described with implications for course performance. These student weaknesses are discussed with respect to sex difference as they relate to learning and instructional activities in introductory chemistry classes. (Author/JN)

College Chemistry and Piaget:
Defining the Sample

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Abstract

Cognitive performance on "An Inventory of Piaget's Developmental Tasks" (IPDT) was related to the Scholastic Aptitude Tests and performance in both college chemistry lecture and laboratory class. The IPDT is a valid and reliable 72-item, untimed, multiple choice paper and pencil inventory with 18 subscales representing different Piagetian tasks. Subjects (_n_ = 225) from two different levels of introductory chemistry courses participated. IPDT scores were significantly correlated with SAT's and placement data. Although correlations with course grades were low, 'A' students were higher than others in Piagetian development, particularly for the higher level course. Males outperformed females on the IPDT even when course grades were similar. Weakest areas of development as indicated by subscale scores are described with implications for course performance. These student weaknesses are discussed with respect to sex differences and course placement. Finally, Piagetian tasks are discussed as they relate to learning and instructional activities in introductory chemistry classes.

College Chemistry and Piaget:

Defining the Sample

For the past several years, researchers in science education have demonstrated that many college freshmen are not able to apply abstract reasoning (Piaget's formal operational thought) to concepts in science courses (Dale, 1970; Dunlap & Fazio, 1976; Elkind, 1962; Lovell, 1961; McKinnon & Renner, 1971). For instance, McKinnon and Renner (1971) found that half of the college freshmen performed at the concrete level of cognitive development. Furthermore, other findings have satisfactorily shown the relationship between Piaget's theory of cognitive functioning and college science teaching (ADAPT, 1977; Arons, 1976; Fuller, Karplus & Lawson, 1977; Herron, 1975; Lawson, 1975; Lawson & Renner, 1975; Renner & Lawson, 1973). For example, Herron (1975) cited activities in general chemistry which students might not be able to perform if they had not reached the stage of formal operations. Moreover, R. G. Fuller and co-workers at University of Nebraska-Lincoln developed the ADAPT program, a Piagetian-based multidisciplinary course of study based on Karplus' learning cycle model (Karplus, 1974). As a result of the increased interest in Piaget's theory as it relates to college science curricula, many standardized instruments measuring cognitive maturation have been developed (Bart, 1972; Burney, 1974; De Avila & Pulos, 1979; Lawson, 1978; Longeot, 1965; Raven, 1973; Rowell & Hoffman, 1975; Shayer & Wharry, 1974; Staver & Gabel, 1979; Tisher, 1971).

Sampling Concerns and Performance Measures

Research attempts to explain variance in science course achievement using measures of Piagetian development have yielded inconsistent findings. This may be due in part to the aptitude or achievement levels of students tested and/or to the measures used to ascertain their course performance. For instance, Herron (1975) found a correlation of 0.7 between a chemistry placement examination and the results of a Piagetian battery of tasks in a sample of higher ability freshmen. The same study reported a correlation of 0.8 between the Piagetian tasks and course performance for chemistry students. Albanese, Brooks, Day, Koehler, Lewis, Marianelli, Rack and Tomlinson-Keasey (1976) report that performance on written Piagetian tasks accounted for little of the variance in general chemistry course grades. A high correlation between Piagetian performance and ACT scores was found for above average students but not below average students in a study by McKinnon and Renner (1971). Williams, Turner, Debreuil, Fast and Berestiansky (1979) reported a correlation of .47 between performance on a test of logical operations and a chemistry midterm examination for a combined sample of college students that included science majors, third-year students and nonmajors. These studies point out the wide variation in samples of college students and measures used to investigate the relationship between Piagetian performance and science achievement.

In recent years, there has been increased concern with abilities and attitudes of women in the sciences and mathematics. This is expressed in part by interest in programs that fund research on the role of women in science such as the National Science Foundation's Women in Science Program and Development in Science Education-Improving Access to Careers in Science for Women. Research by Maccoby and Jacklin (1974) has generally shown that males, as a group, are superior to females in spatial-visual ability and mathematics while females outperform the males on verbal tasks. With respect to college students and Piagetian development, Elkind (1962) found males to be superior in volume conservation. Kelly and Kelly (1978) cite other studies, in addition to their own research, that demonstrate some deficiencies of women as compared to men in performing Piagetian-type tasks. It is likely that traditional sex role typing has resulted in childbearing practices and educational procedures that have limited the opportunities of females to engage in experiences in mathematics and science-related tasks as they age. However, the impact of such differences may not be great in terms of actual achievement if they are attenuated by such factors as motivation and various coping styles.

Problem Statement

Recently, articles by Milakofsky and Patterson (1979) and Patterson and Milakofsky (1980) have shown the validity, reliability and usefulness to chemistry educators of a paper-pencil instrument to assess cognitive development. This group administered test published by Furth (1970) is called An Inventory of Piaget's Developmental Tasks (IPDT). The purpose of this paper is to investigate the relationship of the variables cited in the above research (aptitude, placement examinations, course performance and gender) with a written test of cognitive functioning based upon Piagetian development, the IPDT. We intend to examine these variables in the context of two levels of college chemistry students. The paper will (1) elaborate on the previous work of Milakofsky and Patterson by reporting on the cognitive performance of college science students, (2) relate cognitive functioning to other measures of aptitude and performance, (3) describe the weakest areas of Piagetian development for college students, and (4) discuss sex differences with respect to the IPDT and course performance.

Method

The Inventory of Piaget's Developmental Tasks (IPDT)

The IPDT is a 72-item, untimed, multiple choice, paper-pencil inventory of Piaget's cognitive development. Because the IPDT was originally designed to assess the cognitive performance of Navaho Indian children, subjects with minimal reading comprehension skills could easily understand the questions. Moreover, the IPDT is divided into 18 subtests (4 items per subtest) representing different Piagetian tasks such as conservation of volume, classification, perspective and probability. Patterson and Milakofsky (1980) obtained test-retest coefficients of .67 to .95 and a split-half reliability coefficient of .77 in samples of college students using the IPDT. As for the validity of this instrument, results of the IPDT being administered to third grade through college students were consistent with other Piagetian research. Patterson and Milakofsky also found that the IPDT yielded results similar to individual interviews again in samples of third, sixth and ninth graders as well as college freshmen and sophomores.

Subjects

A total of 225 college students enrolled in two different levels of first year chemistry courses (introductory/remedial and principles of chemistry) participated in the study. These subjects were day and evening students located at two branch campuses of The Pennsylvania State University. Enrollment in one of these two levels of instruction was based upon the combined scores of in-house university-wide chemistry and algebra placement examinations. These placement examinations were designed to assess a student's high school knowledge of chemistry and algebra. Thus, the two groups consisted of:

Group 1. A total of 64 students (34 males and 30 females) registered in the lower level introductory/remedial chemistry course.

Group 2. A total of 161 students (144 males and 17 females) registered in the higher level introductory principles of chemistry course.

Procedure

Within the first two weeks of the term, groups of 25 students or less were read a brief description of the nature and goals of the research. Subjects then signed an informed consent form and reported background information on a personal data sheet. The IPDT test booklets and answer sheets were passed out, followed by verbal instructions on taking the inventory. Although participants were allowed as much time as necessary to finish the inventory, most students completed the IPDT in approximately 45 minutes. Scholastic Aptitude Test (SAT) scores, University placement examination results and science and mathematics course grades were obtained from central records. The inventory was readministered to a sample of 64 students from Group 2 at the end of the same term.

Results

The two levels of chemistry students were first compared to see how they differed on the aptitude measures. As shown in Table 1, the two groups of students are significantly different in

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Insert Table 1 about here

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terms of average SAT mathematical and verbal scores, chemistry placement examinations and the IPDT. Group 1 scores significantly lower on these measures of aptitude and previous knowledge.

The correlations of aptitude and achievement measures are shown in Tables 2 and 3. There was a significant relationship between the IPDT and the other measures of ability--the mathematics

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Insert Tables 2 and 3 about here

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and verbal SAT's and the chemistry placement test. As expected, the correlation between the IPDT and the mathematics SAT was much higher than with the verbal portion. With respect to performance as measured by end-of-term grades in the chemistry courses, the IPDT was significantly correlated with achievement in the higher level course (Group 2) but not the lower level (Group 1). A similar relationship held for the SAT mathematics scores and chemistry course achievement. The relationship of Piagetian development and achievement was approximately the same for both lecture and laboratory classes.

Figure 1 shows the IPDT scores broken down by achievement level in the chemistry courses. Students in Group 2 outperform Group 1 as was shown in Table 1. In both levels of course instruction, the 'A' students do have a higher level of measured cognitive functioning than the remainder of the students. Otherwise, there is no consistent relationship between the IPDT and performance within each course.

Insert Figure 1 about here

In the investigation of subtests, Group 2 students score significantly higher than Group 1 on subtests 7, 8, 9, 12, 13, and 15 as shown in Table 4. With the exception of subtests 6, 10 and 17, the mean subtest scores for Group 2 are higher than those for Group 1. By ranking the subtests using mean scores, we found that subtests 9, 11, 13, 14, 15 and 18 are the six most difficult or weakest in terms of Piagetian development for both groups while subtests 2, 3, 4, 5, 10 and 17 are the six easiest or strongest areas of Piagetian development.

Insert Table 4 about here

The percentages of subjects in each group missing at least half of the items in a particular subtest are shown in Figure 2, again indicating the weakest areas of cognitive functioning which

Insert Figure 2 about here

are conservation of volume (Volume subtest), classification (Classes subtest), conservation of length (Distance subtest) and probability (Probability subtest). By contrast, at least 98% of all subjects (Groups 1 and 2) attained at least half correct per subtest in the six strongest areas of the inventory.

When we looked at each of the four items of the Volume subtest, we found that 85% of the students could correctly answer the first two questions dealing with the concept of water displacement by an object whose shape but not volume had changed. Poorer student results were obtained (70%) for the last two questions when students failed to recognize that the amount of water displaced is a function of the volume of an object (density greater than water) and not its mass. In fact, for the last item, 20% of Group 1 and 14% of Group 2 thought that a lighter (denser than water), larger ball would displace water in a glass but that a smaller, heavier ball <u>would not</u> displace any water.

The objective of the questions in the Rotation subtest (kinetic imagery) was to determine the position of gears after one or more interlocking gears are rotated one or more sprocket positions. (All gear ratios are 1:1.) About 30% of the Group 1 students and 22% of Group 2 students incorrectly answered at least half of the questions in this subtest.

In the Shadows subtest (perspective), subjects need to identify the shape and size of an object's shadow made by either sunlight or candle light. As shown in Figure 2, 27% of Group 1 and 11% of Group 2 missed at least half of the subtest's items. On one of the items, more than 65% of the students incorrectly determined the perspective of a shadow from a house. The distinction in abilities between the two groups is clearly shown in this subtest.

The Classification subtest proved to be the most difficult set of items for students. Success on this subtest depended upon the ability of subjects to hierarchically group objects by shape, size and color. As shown in Figure 2, about 55% of Group 1 and 50% of Group 2 missed at least half of the questions. However, when the IPDT was readministered to students at the end of the term (an interval of about eight weeks from the first administration), the Classification subtest was the only one to result in significantly improved scores, F (1,126) = 6.698, $p < .02$.

The results of the Distance subtest (conservation of length) were strongly influenced by one item that required students to understand that when the shape of a figure changes with a constant perimeter, the area of the figure changes. A large proportion of students (97% of Group 1 and 27% of Group 2) thought that both the area and the perimeter of a figure remain constant while its shape changed.

On the Probability subtest, the subject knows that a box is filled with four to eight balls each having one of three types of surface designs. The student is asked to guess the order in which the balls might be drawn out of the box. As shown in Figure 2, more than 25% of Group 1 and nearly 20% of Group two missed at least half of the questions on probability. It is likely that students neglected the number and kind of the remaining sample of balls after one was drawn out.

Sex differences on the performance and aptitude measures in Group 1 are shown in Table 5. (Group 2 was not included in this analysis of sex differences because of the relatively low number of female subjects.) The IPDT is the only ability test that significantly differentiates students on the basis of gender in

Insert Table 5 about here

this sample. Course performance as measured by end-of-course grades is similar for males and females in both lecture and laboratory classes. Figure 3 compares the performance of males and females according to level of achievement in the introductory chemistry class (Group 1). At each level of performance, females score lower

Insert Figure 3 about here

on the IPDT. With respect to subtests, males significantly outperformed females on Angles (reciprocal implication), $F\ (1, 62) = 10.28$, $p < .005$, Volume (conservation of volume), $F\ (1, 62) = 8.59$, $p < .005$, Quantity (conservation of quantity), $F\ (1, 62) = 4.0$, $p < .05$ and Rotation (kinetic imagery), $F\ (1, 62) = 5.23$, $p < .05$.

Discussion

The significant relationship between the IPDT and the SAT's indicates that this measure of cognitive functioning does have some validity as a predictor of college performance. The correlations of .55 for the mathematics SAT and .24 for the verbal SAT also mean that the IPDT is sufficiently independent of the traditional measures of aptitude for college to warrant further investigation. Herron (1978) has suggested continued research in this area. The correlations between the IPDT and course grades are much lower than those found in other studies (Herron, 1975; Albanese, et al., 1976; Williams, et al., 1979). While this finding may be attributed to the different instrumentation in measuring Piagetian development, generalizations across ill-defined samples are difficult to make. We propose that the greater specification of sample characteristics in this study will lend itself to easier comparisons in future research.

The lack of consistent relationships between the SAT's and performance in the lecture and laboratory courses in this study appears to confirm our concern that placement procedures in college courses limit the generalizability of research findings when common measures (such as SAT's or the ACT) are not used to describe sample characteristics. The abilities of the students as well as level of expected competence in various courses must be taken into account. Finally, the use of correlational statistics in these studies may 'mask' peculiar distinctions among achievement levels such as we found with the higher mean IPDT scores for 'A' students.

The above discussion focuses on comparing the results of this study with other research findings. A second perspective involves the content of introductory courses in terms of instruction and evaluation. The low correlation between course grades and the IPDT may point out that instruction may not depend upon higher levels of cognitive functioning on the part of students as professors present information in class or through textbooks. Cantu and Herron (1978) concluded that the performance of students low in cognitive functioning may be satisfactory if the instructional procedures do not demand intellectual thought at the formal-operational level. Furthermore, evaluation procedures may demand memorization without insight or higher levels of understanding, as suggested by Schullery (1979). We are currently looking at the relationship between the IPDT, the subtests, and course examination items to further pursue the issue of the match between cognitive functioning and course competencies.

The findings with respect to weak areas of cognitive functioning in college students are consistent with the results of previous studies (Milakofsky & Patterson, 1979; Patterson & Milakofsky, 1980). Poor performance on specific subtests can be related to the inability to achieve in college chemistry. For instance, the inability of a student to understand the principle of conservation of volume will lead to poor performance in tasks dealing with density. Since proportional reasoning plays a role in solving metric conversions, mole concepts and stoichiometry, students who were weak on the Rotation (kinetic imagery) subtest would encounter further difficulties in chemistry tasks of this nature. As Herron (1975) points out, teachers would rather use the factor-label method (the algorithm) to solve chemical mathematics problems such as stoichiometry than use proportional reasoning which could only serve to confuse students. The drawing and recognition of stereoisomers and the predicting of shapes of molecules could be strongly influenced by student weaknesses in the area of perspective as measured by the Shadows subtest.

With respect to the classification tasks, the inability to perform here could result in difficulties in distinguishing between examples of elements and compounds, classifying elements and predicting theeir periodic relationships, indentifying compounds by bonding types, and categorizing compounds according to their functional groups. Unsatisfactory performance in tasks involving the examination of the chemical effect of shape changes in surfaces may be indicated when students perform poorly on the conservation of length tasks. Since students in the higher level course performed better on this subtest, any improvement in this area might be a significant factor in preparation for more advanced chemistry courses. Finally, it is possible that students who perform poorly on the Probability subtest will have difficulty in comprehending statistical chemical problems.

We found a sex difference in average IPDT performance with males and females who were similar in verbal and mathematical aptitude as measured by the SAT's The superior performance of males is consistent with the studies by Elkind (1962) and Kelly and Kelly (1978) on college subjects. That sex differences existed on four of the eighteen subtests (average male scores always higher) indicates that researchers need to be more specific in describing sex differences in Piagetian development at the college level. To put this another way, we must also be more comprehensive in breadth of tasks so as to not overgeneralize from such findings of male superiority in volume conception (Elkind) or horizontality (Kelly and Kelly).

That the women in the sample were able to achieve as well as the men in the chemistry courses despite lower scores on the IPDT points to the presence of other factors in women's achievement (Bender, 1977). We might hypothesize that training procedures in the understanding of physical concepts would result in even greater achievement on the part of women.

Conclusion

The identification of deficiencies in the cognitive development of college chemistry students raises two major implications for modifying learning systems at the college level. First, developmental programs may be instituted to improve the cognitive functioning of students. Second, instruction may be modified to de-emphasize formal-operational tasks. As Cantu and Herron (1978) have stated, "If we are to increase comprehension of science, we must either assist students in their development of reasoning or we must learn to teach so that ideas of science are understood by students who remain at the concrete-operational level" (p. 141). There is a lack of research to demonstrate whether or not students in late adolescence can benefit from training programs directed toward enhancing cognitive development. The ADAPT program at the University of Nebraska (Tomlinson-Keasey, 1978) uses Piagetian theory to structure instruction in six content areas including the social sciences,

sciences and humanities. McKinnon and Renner (1971) report that an "inquiry-centered science course" improved the logical thinking of participants. And the goal of the AESOP project at the University of California (Berkeley) is to "extend Piaget's clinical approach with individuals and groups" to the development of science and mathematics curricula (Lawson & Renner, 1975).

However, the results of some studies cast doubt upon the effectiveness of training programs. Tomlinson-Keasey (1972) found that although subjects were able to demonstrate improved conceptual thinking immediately after training procedures, they could not generalize to new tasks after a delayed time period. On volume-conception tasks, a significant proportion of college students failed to master skills after training procedures (Kelly & Kelly, 1978). Finally, there is the question of whether efforts at improving cognitive performance should emphasize general Piagetian tasks as a prerequisite to transfer to content learning or be specifically directed toward particular knowledge acquisition. Our finding that performance on the classification subtest improved from the beginning to the end of a college chemistry might indicate that practice with cognitive tasks within the context of a course could result in the attainment of more general cognitive skills. Seemingly, it is possible to conclude that a freshman chemistry course can enhance cognitive development in the area of classification.

The issue of directing our efforts toward specific knowledge matter relates to the second implication mentioned above--that of restructuring course content to match student levels of cognitive functioning. Herron (1975) lists various activities expected of college chemistry students that demand or do not demand formal-operational thought. It would be a formidable task, however, to determine the level of Piagetian thought required to achieve "true understanding" of a particular "byte" of chemical knowledge, to teach the knowledge at a level using strategies that demanded specific modes of conrete or formal operational thought and then to assess retention of the material with items that could be identified as requiring concrete or formal stages of thinking. The issues involved here are reviewed in Herron (1978) and Kuhn (1979).

In conclusion, we need more information on the benefits of programs directed toward improving general cognitive skills versus those concentrating on preparation for learning specific subject matter. We need to examine the results of programs involving participants who are in their late adolescence to see if the benefits are long-lasting. And finally, further investigation is necessary to develop teaching strategies that can enhance the learning of students who have yet to attain the formal-operational stage of cognitive development.

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Table 1

Mean Standardized Test Scores and IPDT Scores

by Group

Test Name	Group 1[a] $\bar{X}$	Group 1[a] SD	Group 2[b] $\bar{X}$	Group 2[b] SD	F[c]
SAT Mathematics	466	51	579	84	64.93**
SAT Verbal	426	63	476	72	16.14**
Chemistry Placement[d]	-.86	.71	.23	.94	44.54**
IPDT[e]	61.3	5.3	63.8	4.7	11.58*

[a] n = 64.

[b] n = 161.

[c] df = 1, 180.

[d] Standardized T-score with mean of zero.

[e] Maximum score of 72.

*p <.01.

**p <.0001.

Table 2

Pearson Product-Moment Correlation Coefficients of IPDT with Aptitude Measures

	Chemistry Placement		SAT (math)		SAT (verbal)	
	r	*n*	*r*	*n*	*r*	*n*
IPDT	.31*	182	.55*	182	.24*	182
SAT (math)	.52*	175			.47*	182
SAT (verbal)	.32*	175				

*$p < .001$.

Table 3

Pearson Product-Moment Correlation Coefficients

of IPDT and Aptitude Measures with Course Performance

	Lecture Grade		Laboratory Grade	
	r	*n*	*r*	*n*
Group 1				
IPDT	.03	61	.01	61
SAT (math)	.00	40	-.04	40
SAT (verbal)	-.19	40	-.21	40
Group 2				
IPDT	.15*	145	.19*	147
SAT (math)	.33***	133	.24**	134
SAT (verbal)	.17*	131	.00	134

*p<.05.

**p<.005.

***p<.001.

Table 4

Mean Subtest Scores for Groups 1 and 2

Subtest			Group 1[a]		Group 2[b]		
Number	Name	Piagetian Concept	$\bar{X}$	SD	$\bar{X}$	SD	F^c
1	Quantity	Conservation of Quantity	3.45	.59	3.51	.59	.41
2	Levels	Transformational Imagery	3.89	.62	3.94	.38	.48
3	Sequence	Ordinal Relations	3.80	.51	3.86	.47	.71
4	Weight	Conservation of Weight	3.97	.18	3.98	.18	.24
5	Matrix	Classification	3.81	.39	3.89	.40	1.96
6	Symbols	Combinativity	3.72	.58	3.70	.50	.09
7	Perspective	Perspective	3.64	.72	3.81	.50	4.18*
8	Movement	Kinetic Imagery	3.47	.64	3.68	.60	5.68*
9	Volume	Conservation of Volume	2.98	1.13	3.38	.90	7.54**
10	Seriation	Ordinal Relations	3.92	.27	3.89	.38	.28
11	Rotation	Kinetic Imagery	2.95	.97	3.17	.95	2.47
12	Angles	Reciprocal Implication	3.34	.95	3.62	.70	5.85*
13	Shadows	Perspective	2.91	.87	3:17	.68	6.07*
14	Classes	Classification	2.28	1.35	2.41	1.26	.46
15	Distance	Conservation of Length	2.59	.61	2.86	.78	6.16*
16	Inclusion	Verbal Class Inclusion	3.58	.69	3.73	.73	1.95
17	Inference	Transitivity	3.89	.44	3.82	.55	0.85
18	Probability	Probability	3.11	1.14	3.34	1.03	2.07

Note. Maximum Score = 4.

[a]n = 64.

[b]n = 161.

[c]df = 1,223.

*$p < .05$.

**$p < .01$.

Table 5

Sex Differences on Aptitude and Performance Measures

(Group 1)

	$\bar{X}$			
	Males	Females	*F*	df
SAT (math)	480.0	451.1	3.38	38
SAT (verbal)	423.8	427.9	0.04	38
Chemistry Placement[a]	4.90	5.70	0.74	36
IPDT[b]	63.0	59.4	8.36*	62
Lecture Grade[c]	2.03	2.11	0.06	59
Laboratory Grade[c]	3.41	3.26	0.39	59

[a] Maximum score = 20.

[b] Maximum score = 72.

[c] Maximum score of 4 designating 'A' grade.

*$p < .01$.

Figure #1

Average IPDT Scores by Level of Course Performance

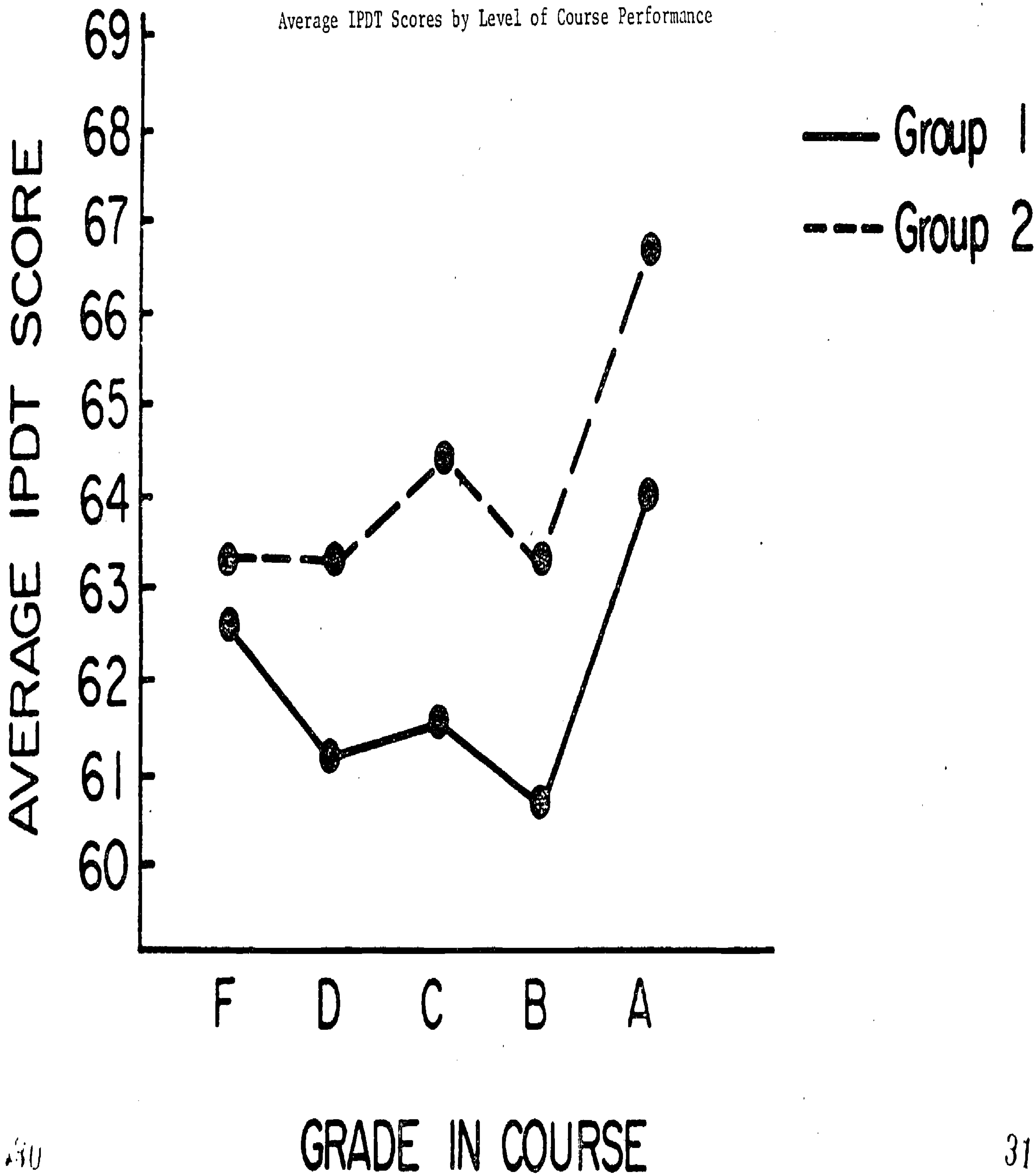

Figure #2

Percentage of Students Missing at Least Half of Subtest

Items in Six Weakest Areas for Each Group

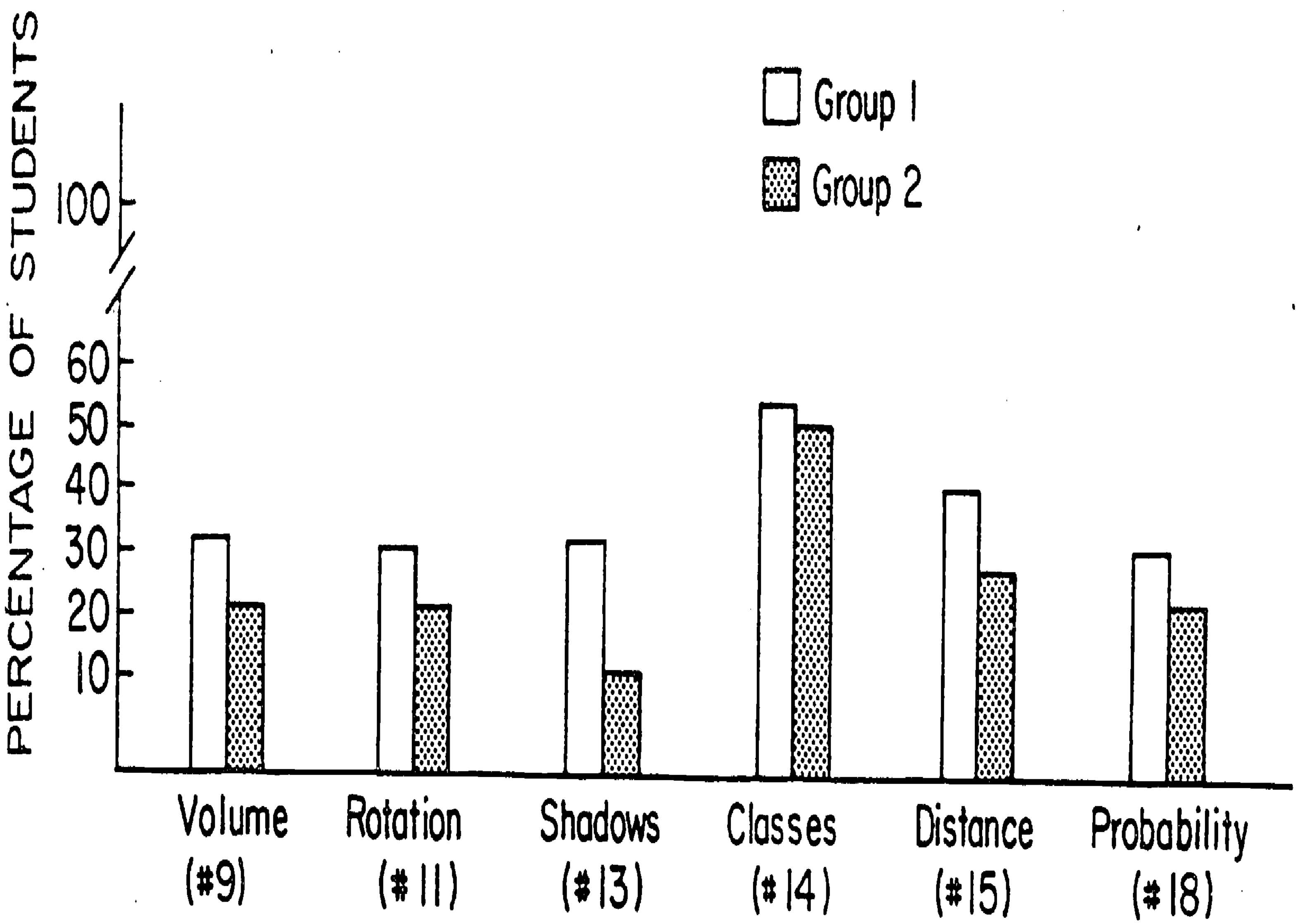

Figure #3

Average IPDT Scores by Sex (Group 1)